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(54) System, method and controller for controlling braking of a wheel of a vehicle

System, Verfahren und Steuerungsgerät zur Bremssteuerung eines Kraftfahrzeugrades

Système et procédé pour commander le freinage d'une roue de véhicule

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Description

Technical Field

[0001] The present invention relates generally to brake systems for vehicles, and more particularly to a brake control system based on torque feedback control.

Background of the Invention

[0002] Brake systems for vehicles (e.g., aircraft, automobiles, etc.) are well known in the art. Most brake systems include a brake actuator for exerting pressure on brake material. The brake material in turn exerts a braking torque on the element to be braked (e.g., the wheel of the vehicle). The brake actuator may be hydraulic or electromechanical, for example. By selectively activating the brake actuator, a desired amount of braking torque, or force, may be applied to the element to be braked.

[0003] In the past, torque feedback has been considered desirable in braking applications to compensate for various effects. For example, brake systems for vehicles have included a controller which utilizes the measured braking torque applied to the wheel to compensate for brake fade (due to thermal effects) and grabby brakes (common with carbon brakes). A torque sensor would measure the torque applied to the wheel and the output of the torque sensor was fed back to the controller.

[0004] Various problems arose, however, as a result of the use of torque feedback. For example, due to sensor noise and physical properties of torque, the output of the torque sensor was not valid at or near zero wheel speed. To account for this, the torque feedback was disabled below a predefined wheel speed and the brake system would revert to open loop control. This "low speed cutout" of the torque feedback control would naturally have to occur at a speed at which the output of the wheel speed sensor was still valid. Since wheel speed sensors typically are valid only to a predefined lower speed limit, the low speed cutout was required to occur at a speed greater than the lower speed limit. Thus, the limitations of the torque sensor and the wheel speed sensor precluded torque compensation at low wheel speeds.

[0005] Another problem with torque feedback using low speed cutout control is that the transition from closed loop control to open loop control has to occur over a period of time. If the pilot of an aircraft or driver of an automobile happens to be activating the brake during this time, a gradual change may be felt. If the pilot or driver does not happen to be operating the brake during the transition period, however, a sudden change may be perceived in the next brake application. This sudden change would present a discontinuity in the braking felt by the pilot/driver and even passengers, creating feelings of discomfort and/or alarm.

[0006] Furthermore, problems occur when proportional-integral (P-I) controllers are used in combination with the low speed cutout. If braking is applied at high speed, the integral portion of the P-I controller will tend to overshoot and cause the brake to grab initially. This can cause a short wheel skid if the surface on which the wheel is running is not dry.

[0007] In view of the aforementioned shortcomings associated with brake systems employing torque feedback control, there is a strong need in the art for a brake system which provides more suitable torque compensation. There is a strong need in the art for a system in which allows torque compensation operation to substantially zero wheel speed. Moreover, there is a strong need for a system in which torque compensation is provided with substantially no discontinuities, regardless of time or torque level. In addition, there is a strong need for a system in which the brakes do not tend to grab as a result of brake material or the integral portion of a P-I controller.

[0008] US-A-4 822 113 discloses a controller having all the features of the preamble of claim 1.

Summary of the Invention

[0009] According to a first aspect of the invention, there is provided a torque level transitioning controller for controlling a braking torque applied to a wheel of a vehicle via a brake actuator and assembly based on an output of a torque sensor which measures an amount of brake torque applied to the wheel, the output of the torque sensor being fed back to the torque level transitioning controller, the torque level transitioning controller comprising: an input for receiving a brake torque command indicative of a desired amount of brake torque to be applied to the wheel, and an output for providing a brake torque output command to the brake actuator and assembly which applies a brake torque to the wheel based on the brake torque output command; another input for receiving the output of the torque sensor; and circuitry for adjusting the brake torque output command provided to the brake actuator and assembly using torque feedback control based on the output received from the torque sensor, characterized in that the torque level transitioning controller is configured so as to limit a degree of the torque feedback control based on the measured amount of brake torque applied to the wheel.

[0010] In accordance with a second aspect of the invention, there is provided a system for controlling a braking torque applied to a wheel of a vehicle, comprising: a controller according to the first aspect of the invention; and a

torque sensor operatively coupled to the brake actuator and assembly and the torque level transitioning controller, for measuring an amount of brake torque applied to the wheel and feeding back a signal to the torque level transitioning controller indicative of the amount of applied brake torque.

[0011] According to a third aspect of the invention, there is provided a method for controlling a braking torque applied to a wheel of a vehicle, comprising the steps of: receiving a brake torque command indicative of a desired amount of brake torque to be applied to the wheel, and providing a brake torque output command to a brake actuator and assembly which applies a brake torque to the wheel based on the brake torque output command; measuring an amount of brake torque applied to the wheel and using a signal indicative of the amount of applied brake torque to perform torque feedback control of the brake torque output command; and adjusting the brake torque output command provided to the brake actuator using the torque feedback control based on the measured amount of brake torque, the adjusting step including a step of limiting a degree of the torque feedback control based on the amount of brake torque applied to the wheel.

[0012] According to preferred embodiments of the invention, a brake system and torque feedback controller is provided which utilizes low torque cutout rather than low speed cutout. The low torque cutout is further improved by gradually transitioning between torque feedback and open loop control over a range of torque. In appropriate embodiments, the controller of the present invention allows torque compensation operation to zero wheel speed, and avoids discontinuities in braking regardless of time or torque level. Also the controller can allow a brake to fill and engage the wheel before the full feedback signal is presented to the controller so as to eliminate the phenomena of grabby brakes.

[0013] To the accomplishment of the foregoing and related ends, the invention, then, comprises the features defined in the claims. The following description and the annexed drawings set forth in detail certain illustrative embodiments of the invention. These embodiments are indicative, however, of but a few of the various ways in which the principles of the invention may be employed. Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

Brief Description of the Drawings

[0014]

Fig. 1 is a block diagram of a brake system incorporating torque feedback control using torque level transitioning in accordance with the present invention;

Fig. 2 is a schematic diagram of a torque level transitioning controller in accordance with the present invention for use in an embodiment having a pressure valve application based brake system;

Fig. 3 is a schematic diagram of a torque level transitioning controller in accordance with the present invention for use in an embodiment having a flow valve application based brake system;

Fig. 4a is a plot showing the torque feedback versus measured torque for a constant torque command;

Fig. 4b is a plot showing the controller error versus measured torque corresponding to the plot shown in Fig. 4a;

Fig. 5 is a plot showing requested torque, measured pressure, and measured torque according to one example of the present invention; and

Fig. 6 is a plot showing requested torque, measured pressure, and measured torque using a conventional controller.

Description of the Preferred Embodiments

[0015] The present invention will now be described with reference to the figures in which like reference numerals are used to refer to like elements throughout.

[0016] Referring initially to Fig. 1, a brake control system with torque compensation for an aircraft in accordance with the present invention is generally designated 10. Brake control on an aircraft is usually structured in a paired wheel configuration for functional modularity. For example, if the aircraft has two wheels on the left side of the aircraft and two wheels on the right side, the outer two wheels form a pair and the inner two wheels form another pair. Within a pair there is a right wheel control and left wheel control. The left and right wheel control functions are uncoupled except for locked wheel protection. The basic unit therefore consists of control of a single wheel which can be left or right. As utilized herein, it will be appreciated that the term "wheel" is intended to refer collectively to both the wheel and tire.

[0017] For sake of simplicity, the brake control system 10 as shown in Fig. 1 represents the basic unit for providing brake control of a single wheel (left or right). However, it will be appreciated that control for the other wheel(s) can be provided via corresponding systems 10 or in a single system incorporating the same inventive principles. Moreover, the preferred embodiment of the present invention provides brake control in connection with an aircraft. Nevertheless, it will be appreciated that the brake control system with torque compensation according to the present invention has utility for virtually any type of vehicle and is not limited necessarily to brake control for aircraft.

[0018] The system 10 includes a pilot brake device 12 for providing operator brake control. In addition, the system

10 includes a torque level transitioning controller 14. The controller 14 controls the amount of torque applied by the braking system 10 as is described more fully below. Specifically, the controller 14 provides a control signal to a brake actuator 16 included in the system 10. The brake actuator 16 may be any conventional type actuator (e.g., hydraulic, electromechanical, or pneumatic) for applying pressure to the brake material (not shown) in a brake assembly 18. The brake assembly 18 in turn provides braking action to a wheel 20 by exerting a braking torque on the wheel 20 as is conventional.

[0019] The system 10 further includes a brake torque sensor 22 which measures the amount of torque exerted by the brake actuator 16 and brake assembly 18 on the wheel 20. The measured torque is input to the controller 14. As will be discussed in detail below, the controller 14 uses torque compensation to control the amount of braking applied to the wheel 20. Unlike systems which utilize a low speed cutout approach to disable the torque compensation, the present invention is not reliant on wheel speed. Rather, the present invention utilizes what is referred to as "low torque cutout" in which the controller 14 disabtes torque compensation based on low measured torque. In addition, the low torque cutout is further improved by the controller 14 gradually transitioning between torque feedback and open loop control over a range of torque as will be discussed.

[0020] Generally describing the operation of the system 10, the pilot brake device 12 comprises a pedal or equivalent thereof. During braking, the pilot of the aircraft activates the pilot brake device 12 by pushing the pedal (or its equivalent). The depression of the pedal is converted to an electrical signal (brake torque command signal T_c) which is provided to the controller 14. The value of the command signal T_c is indicative of the degree of depression of the pedal, and is related to the amount of brake torque requested by the pilot as is conventional.

[0021] As will be described more fully below in connection with Figs. 2 and 3, the controller 14 outputs a brake torque output command T_{output} to the brake actuator 16 which is based on the value of the brake torque command T_c. Responsive to the output command T_{output}, the brake actuator 16 applies pressure to the brake material in the brake assembly 18. Such pressure results in a brake torque being applied to the wheel 20 in order to slow the speed of the wheel 20. The torque sensor 22 detects the amount of torque presently exerted on the wheel 20 and provides as an output a signal T_m indicative of the measured amount of torque. The signal T_m is fed back to the controller 14 as shown, and is used by the controller 14 to perform torque feedback control.

[0022] Fig. 2 illustrates in detail a first embodiment of the torque controller 14. In this embodiment, the controller 14 is used to control a hydraulic pressure valve (not shown) in the brake actuator 16. As is known, by controlling the pressure valve the amount of pressure applied by the brake actuator 16 to the brake material is controlled. Accordingly, the output T_{output} of the controller 14 is provided to the pressure valve in the brake actuator 16 in order to control the braking torque.

[0023] The command signal T_c representing the desired amount of brake torque is input to a summer 30. The summer 30 compares the command signal T_c to a torque feedback signal T_{fb} which is provided to a negative input of the summer 30. The output of the summer 30 represents a torque error signal T_{error}. The signal T_{error} is input to a proportional gain amplifier 32 and to an integral gain amplifier 34 which are respectively included in the proportional and integral portions of a P-I controller as is known.

[0024] The proportional gain amplifier 32 preferably has a preselected gain which is less than unity, and outputs a signal which is always proportional to the torque error signal T_{error}. The integral gain amplifier 34 also has a preselected gain of less than one and provides as its output a scaled value of the current torque error signal T_{error}. The output of the integral gain amplifier 34 is coupled to a limited integrator 36 included in the integral portion of the controller 14. Specifically, the integral gain amplifier 34 provides the scaled value of the current torque error signal T_{error} to a first input of a summer 38. The output of the summer 38 is input to a limiter 40 which limits the output of the summer 38 between a preselected maximum value (max) and a preselected minimum value (min) in order to limit the range of applied torque. The output of the limiter 40 is provided to a summer 42 which combines the output of the limiter 40 with the output of the proportional gain amplifier 32. The summer 42 provides as its output the brake torque output command T_{output} to the brake actuator 16.

[0025] The output of the limiter 40 is also fed back through an integrator block 44 which, in the digital domain, provides as its output signal T_{prov} which represents the last integrator output from the limiter 40 (e.g., from the previous sample). The output T_{prev} from the integrator block 44 is then input to the summer 38 where it is added to the output of integral gain amplifier 34, thus completing the integral portion of the P-I controller.

[0026] As will be appreciated, the output signal T_{prev} of the integrator block 44 represents generally the brake torque output command of the controller 14 during the last control sample (less the proportional component). The output signal T_{prev} is input to a transition function block 48 which is also included in the controller 14. The transition function block 48 combines the output signal T_{prev} from the integrator block 44 together with the measured torque signal T_m from the torque sensor 22 and the limited measured torque T_{llm}, in order to determine whether the controller 14 operates with torque feedback or open loop control. Specifically, the measured torque signal T_m is input to the transition function block 48. In addition, the measured torque signal T_m is input to a limiter 50 which limits the value of the measured torque to a predefined range having a minimum (e.g., zero) and a maximum (r). The limited measured torque T_{llm} is

then output from the limiter 50 to the transition function block 48. The transition function block 48 combines the respective signals as discussed below to produce the torque feedback signal T_{fb} which is output to the negative terminal of the summer 30 as mentioned above.

[0027] In order to better understand the principles behind the operation of the transition function block 48, which may be implemented using a microprocessor the like, the following technical background is considered helpful: To vary the influence of two signals on a function, the following method can be used:

$$Y(A,B) = Ax + B(1-x) \quad \text{Equ. 1}$$

where Y(A,B) is the output, A and B are the inputs, and x is a number that varies between zero and one. The value of x controls the influence of A and B on the output.
If it is desired that A be used to control the influence of the inputs on the output, then Equ. 1 can be expressed as:

$$Y(A,B) = A^2 - AB + B \quad \text{Equ. 2}$$

where A and B are normalized to one and A equals x from Equ. 1.
This approach varies the control over the entire range of the input A. It may be more desirable to vary the influence of the signals over a narrower range. If the range is defined as zero to r, then the following method can be employed:

if $A < r$, then $C = A$
if $A > r$, then $C = r$,

and hence Equ. 2 can be rewritten as:

$$Y(A,B) = AC/r + B - BC/r = B + CA/r - CB/r \quad \text{Equ. 3}$$

[0028] Applying Equ. 3 to the torque level transitioning controller 14 of the embodiment of Fig. 2, where:

A represents the measured torque T_m;
B represents the previous torque T_{prev};
C represents the limited measured torque T_{lim};
r represents the upper limit of the range 0 to r of the limited measured torque T_{lim}; and
Y(A,B) represents the torque feedback signal T_{fb},

the transfer function block 48 is configured to carry out Equ. 3 as follows:

$$T_{fb} = T_{prev} + T_{lim}T_m/r - T_{lim}T_{prev}/r \quad \text{Equ. 4}$$

[0029] As will be appreciated, if the measured torque T_m approaches zero so will the limited measured torque T_{lim}. Thus, as is noted from Equ. 4, if the measured torque T_m approaches zero the torque feedback signal T_{fb} will approach T_{prev}, or open loop control independent of the measured brake torque (i.e., no torque compensation). As the measured brake torque T_m increases beyond the value of r, the torque feedback signal T_{fb} becomes equal to the measured torque T_m representing full closed loop control based on the measured brake torque. In between a measured brake torque T_m of zero and r (the defined range), the torque feedback signal gradually transitions between open and closed loop control.

[0030] In such manner, the controller 14 provides torque compensation to substantially zero wheel speed as it is not necessary to perform low-speed cutout. Instead, the controller 14 reduces the torque compensation as the measured torque decreases. Above a predefined threshold r, the controller 14 provides closed loop control based on the measured torque to provide full torque compensation. Within the range from zero to r, the torque feedback gradually transitions between closed loop and open loop control. Thus, discontinuities in brake feel are eliminated or reduced, regardless of time or torque level. Moreover, by applying the torque level transitioning the hydraulic brake assembly 18 as driven by the actuator 16 is allowed to fill before the full feedback signal T_{fb} is presented to the controller eliminating the phenomena of grabby brakes. Such fill compensation occurs at both low speed and high speed.

[0031] Fig. 3 illustrates another embodiment of the controller 14 for use with a brake actuator 16 which includes a flow control valve (not shown). As is known, some types of brake actuators 16 include a flow control valve which controls the flow of hydraulic fluid provided to the brake assembly 18 to produce braking torque. The embodiment of Fig. 3 is substantially the same as the embodiment of Fig. 2, and hence only the differences will be discussed herein for sake of brevity.

[0032] The embodiment of Fig. 3 includes a pressure sensor 60 (shown in phantom in Fig. 1) for measuring the hydraulic brake pressure created by the brake actuator 16 as a result of controlling the flow control valve using the brake torque command T_{output}. The output P_m of the sensor 60 represents the hydraulic brake pressure provided to the brake assembly 18, and is fed back to the controller 14 (again as shown in phantom in Fig. 1). Thus, rather than using the output of the integrator block 44 as an input to the transition function block 48 representative of the previously applied torque, the measured pressure P_m is utilized in lieu thereof. Preferably the gains for the pressure sensor 60 and the torque sensor 22 are set up so as to have equal full scale values.

[0033] Applying Equ. 3 to the torque level transitioning controller 14 of the embodiment of Fig. 3, where:

A represents the measured torque T_m;
B represents the measured pressure P_m;
C represents the limited measured torque T_{lim};
r represents the upper limit of the range 0 to r of the limited measured torque T_{lim}; and
Y(A,B) represents the torque feedback signal T_{fb},

the transfer function block 48 is configured to carry out Equ. 3 as follows:

$$T_{fb} = P_m + T_{lim}T_m/r - T_{lim}P_m/r \qquad \text{Equ. 5}$$

[0034] Consequently, if the measured torque T_m approaches zero so will the limited measured torque T_{lim}. Thus, as is noted from Equ. 5, if the measured torque T_m approaches zero the torque feedback signal T_{fb} will approach P_m, or open loop torque control independent of the measured brake torque. At the same time, the system effectively transitions into closed loop pressure control based on P_m. As the measured brake torque T_m increases beyond the value of r, the torque feedback signal T_{fb} becomes equal to the measured torque T_m representing full closed loop torque control based on the measured brake torque. In between a measured brake torque T_m of zero and r (the defined range), the torque feedback signal gradually transitions between open and closed loop control.

[0035] As a result, the embodiment of Fig. 3 provides the same advantageous features as the embodiment of Fig. 2 discussed above.

[0036] Fig. 4a represents a plot of torque feedback T_{fb} versus measured torque T_m which illustrates the effect of the controller 14 in an open loop to closed loop transition. For an eight bit controller 14, the torque command T_c in the example of Fig. 4a is given to be constant at 128 units (half scale). The value of r is preselected to be 64. It is also assumed that the controller 14 is in a steady state condition, e.g., the controller output T_{output} equals the requested torque command T_c. As is shown in Fig. 4a, the torque feedback signal T_{fb} gradually transitions from the steady state condition value of 128 to 64 as the measured torque (also having a full scale value of 256 units) increases from 0 to 64 units. As the measured torque T_m increases beyond 64 units, the controller 14 operates in full closed loop fashion and the torque feedback signal T_{fb} increases linearly with the measured torque T_m. Similarly, if the measured torque T_m were to decrease the feedback signal T_{fb} would decrease linearly for values above r. However, as the measured torque T_m decreases below r the measured torque feedback signal T_m is gradually cut out until the measured torque T_m reaches zero.

[0037] Fig. 4b represents the error signal T_{error} plotted as a function of the measured torque T_m under the same conditions set forth with respect to Fig. 4a. It is noted that the error signal T_{error} is limited by the open loop control until the measured torque T_m increases beyond 64 (the value of r).

[0038] Fig. 5 is a plot illustrating the operation of the controller 14 in accordance with the embodiment of Fig. 3. The plot shown in Fig. 5 is to be compared with the plot shown in Fig. 6 which illustrates the corresponding operation of a controller which does not include torque level transitioning feedback in accordance with the invention. Most notably, the controller represented in Fig. 6 exhibits large torque and pressure spikes (generally labeled as SP) at the application of braking from zero. Such spikes are avoided in the present invention as illustrated in Fig. 5.

[0039] Thus, it will be appreciated that the brake system with torque feedback control using torque level transitioning provides suitable torque compensation even to zero wheel speed. Moreover, by gradually transitioning between closed loop control and open loop control over a range of torque, smooth continuous braking is achievable.

[0040] . Although the invention has been shown and described with respect to certain preferred embodiments, it is

obvious that equivalents and modifications will occur to others skilled in the art upon the reading and understanding of the specification. For example, Equ. 1 above assumes a linear relationship between the two signals which influence the function. Higher order relationships may be utilized without departing from the scope of the invention. In addition, in the above examples torque cutout is performed within the range of zero to r. However, in another embodiment a different range from q to r may be defined where q is non-zero. Such an embodiment may be useful in the event full torque cutout is desired to occur prior to the measured torque reaching zero.

[0041] In another embodiment, a control mechanism other than the P-I type controller described above could be used to implement the invention. For example, a PID type controller may be employed without departing from the scope of the invention. Also, the control method of the present invention may be employed using parameters other than torque, particularly for vehicles which do not have torque sensors. For example, braking may be controlled based on feedback relating to the acceleration of the vehicle. An accelerometer or other means for sensing acceleration provides a feedback signal in place of the torque sensor. The level transitioning controller determines the amount of feedback associated with the sensed acceleration using the same principles described above in place of the torque feedback signal.

[0042] The present invention includes all such equivalents and modifications, and is limited only by the scope of the following claims.

Claims

1. A torque level transitioning controller (14) for controlling a braking torque applied to a wheel (20) of a vehicle via a brake actuator and assembly (16) based on an output of a torque sensor (22) which measures an amount of brake torque applied to the wheel (20), the output of the torque sensor (22) being fed back to the torque level transitioning controller (14), the torque level transitioning controller (14) comprising:

   an input for receiving a brake torque command indicative of a desired amount of brake torque to be applied to the wheel, and an output for providing a brake torque output command to the brake actuator and assembly which applies a brake torque to the wheel based on the brake torque output command;
   another input for receiving the output of the torque sensor; and
   circuitry for adjusting the brake torque output command provided to the brake actuator and assembly using torque feedback control based on the output received from the torque sensor,

   characterized in that
   the torque level transitioning controller (14) is configured so as to limit a degree of the torque feedback control based on the measured amount of brake torque applied to the wheel (20).

2. The controller of claim 1, wherein the torque level transitioning controller tends toward applying open loop control without the torque feedback control based on detection of a low value of brake torque applied to the wheel.

3. The controller of claim 2, wherein the torque level transitioning controller fully employs the torque feedback control based on the signal from the torque sensor as a result of the signal exceeding a predetermined threshold.

4. The controller of claim 1, wherein the circuitry for adjusting the brake torque output command transitions between substantially open loop control of the brake torque output command independent of the measured brake torque and substantially closed loop feedback control of the brake torque output command based on the measured brake torque as a function of the measured brake torque.

5. The controller of claim 4, wherein the torque level transitioning controller transitions between substantially open loop control of the brake torque output command and substantially closed loop feedback control of the brake torque output command over a range of measured brake torque as a function of the measured brake torque.

6. The controller of claim 5, wherein the function is represented by a first order equation.

7. The controller of claim 5, wherein the function is represented by a second order equation or higher order equation.

8. The controller of claim 4, wherein a rate at which the torque level transitioning controller transitions is controlled.

9. The controller of claim 1, wherein the controller becomes less responsive or irresponsive to the measured amount

of brake torque applied to the wheel at low braking torque levels.

10. A system for controlling a braking torque applied to a wheel of a vehicle, comprising:

the controller of claim 1; and
a torque sensor, operatively coupled to the brake actuator and assembly and the torque level transitioning controller, for measuring an amount of brake torque applied to the wheel and feeding back a signal to the torque level transitioning controller indicative of the amount of applied brake torque.

11. The system of claim 10, wherein the torque level transitioning controller tends toward applying open loop control without the torque feedback control based on detection of a low value of brake torque applied to the wheel.

12. The system of claim 11, wherein the torque level transitioning controller fully employs the torque feedback control based on the signal from the torque sensor as a result of the signal exceeding a predetermined threshold.

13. The system of claim 10, wherein the brake torque output command is operative to control a pressure valve included in the brake actuator and assembly.

14. The system of claim 10, wherein the brake torque output command is operative to control a flow valve included in the brake actuator and assembly.

15. The system of claim 14, further comprising a pressure sensor for measured pressure of a fluid controlled by the flow valve, the pressure being indicative of an amount of brake force applied to the wheel, and wherein the torque level transitioning controller receives the output from the pressure sensor to perform closed loop pressure control at low torque levels.

16. The system of claim 10, wherein the vehicle is an aircraft.

17. The system of claim 10, wherein the vehicle is an automobile.

18. The system of claim 10, wherein the torque level transitioning controller transitions between substantially open loop control of the brake torque output command independent of the measured brake torque and substantially closed loop feedback control of the brake torque output command based on the measured brake torque as a function of the measured brake torque.

19. The system of claim 18, wherein the torque level transitioning controller transitions between substantially open loop control of the brake torque output command and substantially closed loop feedback control of the brake torque output command over a range of measured brake torque as a function of the measured brake torque.

20. The system of claim 19, wherein the function is represented by a first order equation.

21. The system of claim 19, wherein the function is represented by a second order equation or higher order equation.

22. The system of claim 18, wherein a rate at which the torque level transitioning controller transitions is controlled.

23. The system of claim 18, wherein the vehicle is an aircraft.

24. The system of claim 18, wherein the vehicle is an automobile.

25. A method for controlling a braking torque applied to a wheel (20) of a vehicle, comprising the steps of:

receiving a brake torque command indicative of a desired amount of brake torque to be applied to the wheel (20), and providing a brake torque output command to a brake actuator and assembly (16) which applies a brake torque to the wheel (20) based on the brake torque output command;
measuring an amount of brake torque applied to the wheel (20) and using a signal indicative of the amount of applied brake torque to perform torque feedback control of the brake torque output command; and
adjusting the brake torque output command provided to the brake actuator (16) using the torque feedback control based on the measured amount of brake torque, the adjusting step including a step of limiting a degree

of the torque feedback control based on the amount of brake torque applied to the wheel.

26. The method of claim 25, wherein the step of limiting includes transitioning toward applying open loop control without the torque feedback control based on detection of a low value of brake torque applied to the wheel.

27. The method of claim 26, wherein the step of limiting includes fully employing the torque feedback control based on the signal from the torque sensor as a result of the signal exceeding a predetermined threshold.

28. The method of claim 25, wherein the adjusting step further includes transitioning between substantially open loop control of the brake torque output command independent of the measured brake torque and substantially closed loop feedback control of the brake torque output command based on the measured brake torque as a function of the measured brake torque.

29. The method of claim 28, wherein the transitioning step includes transitioning between substantially open loop control of the brake torque output command and substantially closed loop feedback control of the brake torque output command over a range of measured brake torque as a function of the measured brake torque.

Patentansprüche

1. Drehmomentpegelübergangscontroller (14) zum Steuern eines Bremsdrehmoments, das auf ein Rad (20) eines Fahrzeugs durch eine Bremsbetätigungseinrichtung und -anordnung (16) basierend auf einem Ausgangssignal eines Drehmomentsensors (22) aufgebracht wird, welcher den Betrag des auf das Rad (20) aufgebrachten Bremsdrehmoments mißt, wobei das Ausgangssignal des Drehmomentsensors (22) zum Drehmomentpegelübergangscontroller (14) zurückgeführt wird, wobei der Drehmomentpegelübergangscontroller (14) aufweist:

einen Eingang zum Empfangen eines Bremsdrehmomentbefehls, der den Betrag des auf das Rad aufzubringenden Bremsdrehmoments angibt, und einen Ausgang zum Liefern eines Bremsdrehmomentausgangsbefehls an die Bremsbetätigungseinrichtung und -anordnung, welche ein Bremsdrehmoment basierend auf dem Bremsdrehmomentausgangsbefehl an das Rad aufbringt;

einen weiteren Eingang zum Empfangen des Ausgangssignals des Drehmomentsensors; und

Schaltungen zum Einstellen des an die Bremsbetätigungseinrichtung und -anordnung gelieferten Bremsdrehmomentausgangsbefehls unter Verwendung von Drehmomentrückkopplungssteuerung basierend auf dem vom Drehmomentsensor gelieferten Ausgangssignal,

dadurch gekennzeichnet, daß
der Drehmomentpegelübergangscontroller (14) derart ausgebildet ist, daß er den Grad der Drehmomentrückkopplungssteuerung basierend auf dem gemessenen Betrag an auf das Rad (20) aufgebrachtem Bremsdrehmoment begrenzt.

2. Controller nach Anspruch 1, bei dem der Drehmomentpegelübergangscontroller bei Erkennung eines niedrigen Werts eines auf das Rad aufgebrachten Drehmoments eine Steuerung mit offener Regelschleife ohne Drehmomentrückkopplung ausführt.

3. Controller nach Anspruch 2, bei dem der Drehmomentpegelübergangscontroller die Drehmomentrückkopplungssteuerung basierend auf dem Signal des Drehmomentsensors voll anwendet, wenn das Signal einen vorbestimmten Schwellenwert übersteigt.

4. Controller nach Anspruch 1, bei dem die Schaltung zum Einstellen des Bremsdrehmomentausgangsbefehls zwischen einer Steuerung des Bremsdrehmomentausgangsbefehls mit im wesentlichen offener Regelschleife unabhängig vom gemessenen Bremsdrehmoment und einer Regelung des Bremsdrehmomentausgangsbefehls unter Rückkopplungsregelung mit im wesentlichen geschlossener Regelschleife basierend auf dem gemessenen Bremsdrehmoment als Funktion des gemessenen Bremsdrehmoments wechselt.

5. Controller nach Anspruch 4, bei dem der Drehmomentpegelübergangscontroller zwischen einer Steuerung des Bremsdrehmomentausgangsbefehls mit im wesentlichen offener Regelschleife und einer Regelung des Brems-

drehmomentausgangsbefehls mit im wesentlichen geschlossener Regelschleife über einen Bereich gemessenen Drehmoments als Funktion des gemessenen Bremsdrehmoments wechselt.

6. Controller nach Anspruch 5, bei dem die Funktion durch eine Gleichung erster Ordnung wiedergegeben ist.

7. Controller nach Anspruch 5, bei dem die Funktion durch eine Gleichung zweiter Ordnung oder eine Gleichung höherer Ordnung wiedergegeben ist.

8. Controller nach Anspruch 4, bei dem die Rate, mit der der Drehmomentpegelübergangscontroller wechselt, gesteuert ist.

9. Controller nach Anspruch 1, bei dem der Controller weniger empfindlich oder unempfindlich für den gemessenen Betrag des bei niedrigen Bremsdrehmomentpegeln auf das Rad aufgebrachten Drehmoments.

10. System zum Steuern eines auf ein Rad eines Fahrzeugs aufgebrachten Bremsdrehmoments, mit:

    dem Controller von Anspruch 1; und

    einem mit der Bremsbetätigungseinrichtung und -anordnung und dem Drehmomentpegelübergangscontroller in Wirkverbindung stehenden Drehmomentsensor zum Messen des Betrags des auf das Rad aufgebrachten Drehmoments und zum Rückkoppeln eines Signals zum Drehmomentpegelübergangscontroller, das den Betrag des aufgebrachten Bremsdrehmoments angibt.

11. System nach Anspruch 10, bei dem der Drehmomentpegetübergangscontroller zur Anwendung einer Steuerung mit offener Regelschleife ohne Drehmomentrückkopplungssteuerung basierend auf der Erkennung eines niedrigen Werts eines auf das Rad aufgebrachten Drehmoments neigt.

12. System nach Anspruch 11, bei dem der Drehmomentpegelübergangscontroller die Drehmomentrückkopplungsregelung basierend auf dem Signal des Drehmomentsensors voll anwendet, wenn das Signal einen vorbestimmten Schwellenwert übersteigt.

13. System nach Anspruch 10, bei dem der Bremsdrehmomentausgangsbefehl ein Druckventil in der Bremsbetätigungseinrichtung und -anordnung steuert.

14. System nach Anspruch 10, bei dem der Bremsdrehmomentausgangsbefehl ein Durchflußventil in der Bremsbetätigungseinrichtung und -anordnung steuert.

15. System nach Anspruch 14, ferner mit einem Drucksensor für den gemessenen Druck eines durch das Durchflußventil geregelten Fluids, wobei der Druck den Betrag an auf das Rad aufgebrachter Bremskraft angibt, und wobei der Drehmomentpegelübergangscontroller das Ausgangssignal des Drucksensors empfängt, um eine Druckregelung bei niedrigen Drehmomentpegeln durchzuführen.

16. System nach Anspruch 10, bei dem das Fahrzeug ein Flugzeug ist.

17. System nach Anspruch 10, bei dem das Fahrzeug ein Automobil ist.

18. System nach Anspruch 10, bei dem der Drehmomentpegelübergangscontroller zwischen einer Steuerung des Bremsdrehmomentausgangsbefehls mit im wesentlichen offener Regelschleife unabhängig vom gemessenen Bremsdrehmoment und einer Regelung des Bremsdrehmomentausgangsbefehls mit im wesentlichen geschlossener Regelschleife basierend auf dem gemessenen Bremsdrehmoment als Funktion des gemessenen Bremsdrehmoments wechselt.

19. System nach Anspruch 18, bei dem der Drehmomentpegelübergangscontroller zwischen einer Steuerung des Bremsdrehmomentausgangsbefehls mit im wesentlichen offener Regelschleife und einer Regelung des Bremsdrehmomentausgangsbefehls mit im wesentlichen geschlossener Regelschleife über einen Bereich gemessenen Drehmoments als Funktion des gemessenen Bremsdrehmoments wechselt.

20. System nach Anspruch 19, bei dem die Funktion durch eine Gleichung erster Ordnung wiedergegeben ist.

21. System nach Anspruch 19, bei dem die Funktion durch eine Gleichung zweiter Ordnung oder eine Gleichung höherer Ordnung wiedergegeben ist.

22. System nach Anspruch 18, bei dem die Rate, mit der der Drehmomentpegelübergangscontroller wechselt, gesteuert ist.

23. System nach Anspruch 18, bei dem das Fahrzeug ein Flugzeug ist.

24. System nach Anspruch 18, bei dem das Fahrzeug ein Automobil ist.

25. Verfahren zum Steuern eines auf ein Rad eines Fahrzeugs aufgebrachten Bremsdrehmoments mit den folgenden Schritten:

Empfangen eines Bremsdrehmomentbefehls, der einen gewünschten Betrag von auf das Rad (20) aufgebrachtem Drehmoment angibt, und Liefern eines Bremsdrehmomentausgangsbefehls an eine Bremsbetätigungseinrichtung und -anordnung (16), welche ein Bremsdrehmoment auf das Rad (20) basierend auf dem Bremsdrehmomentausgangsbefehl aufbringt;

Messen eines Betrags an auf das Rad (20) aufgebrachtem Drehmoment und Verwenden eines den Betrag des aufgebrachten Drehmoments angebenden Signals, um eine Drehmomentrückkopplungsregelung des Bremsdrehmomentausgangsbefehls durchzuführen; und

Anpassen des an die Bremsbetätigungseinrichtung (16) gelieferten Bremsdrehmomentausgangsbefehls unter Verwendung der Drehmomentrückkopplungsregelung basierend auf dem gemessenen Betrag des Bremsdrehmoments, wobei der Schritt des Anpassens den Schritt des Begrenzens des Grads der Drehmomentrückkopplungsregelung basierend auf dem Betrag des auf das Rad aufgebrachten Bremsdrehmoments umfaßt.

26. Verfahren nach Anspruch 25, bei dem der Schritt des Begrenzens das Wechseln zur Anwendung von Steuerung mit offener Regelschleife ohne Drehmomentrückkopplung bei Erkennung eines niedrigen Werts des auf das Rad aufgebrachten Drehmoments umfaßt.

27. Verfahren nach Anspruch 26, bei dem der Schritt des Begrenzens das volle Anwenden der Drehmomentrückkopplungsregelung basierend auf dem Signal des Drehmomentsensors als Folge des Überschreitens eines vorbestimmten Schwellenwerts umfaßt.

28. Verfahren nach Anspruch 25, bei dem der Schritt des Anpassens ferner das Wechseln zwischen einer Steuerung des Bremsdrehmomentausgangsbefehls mit im wesentlichen offener Regelschleife unabhängig vom gemessenen Bremsdrehmoment und einer Regelung des Bremsdrehmomentausgangsbefehls mit im wesentlichen geschlossener Regelschleife basierend auf dem gemessenen Bremsdrehmoment als Funktion des gemessenen Bremsdrehmoments umfaßt.

29. Verfahren nach Anspruch 28, bei dem der Schritt des Wechselns das Wechseln zwischen einer Steuerung des Bremsdrehmomentausgangsbefehls mit im wesentlichen offener Regelschleife und einer Regelung des Bremsdrehmomentausgangsbefehls mit im wesentlichen geschlossener Regelschleife über einen Bereich gemessenen Drehmoments als Funktion des gemessenen Bremsdrehmoments umfaßt.

Revendications

1. Unité de commande de transition de niveau de couple (14) destinée à commander un couple de freinage appliqué sur une roue (20) d'un véhicule par l'intermédiaire d'un actionneur et ensemble de freinage (16) sur la base d'une sortie d'un capteur de couple (22) qui mesure une valeur de couple de freinage appliqué sur la roue (20), la sortie du capteur de couple (22) étant réinjecté à l'unité de commande de transition de niveau de couple (14), l'unité de commande de transition de niveau de couple (14) comprenant ;

une entrée destinée à recevoir une instruction de couple de freinage représentative d'une valeur désirée d'un couple de freinage à appliquer sur la roue, et une sortie destinée à délivrer une instruction de sortie de couple de freinage à l'actionneur et ensemble de freinage qui applique un couple de freinage sur la roue, sur la base de

l'instruction de sortie de couple de freinage ;

une autre entrée destinée à recevoir la sortie du capteur de couple ; et

des circuits destinés à régler l'instruction de sortie de couple de freinage délivrée à l'actionneur et ensemble de freinage en utilisant une commande d'asservissement de couple sur la base de la sortie reçue à partir du capteur de couple,

caractérisée en ce que

l'unité de commande de transition de niveau de couple (14) est configurée de manière à limiter un degré de commande d'asservissement de couple sur la base de la valeur mesurée du couple de freinage appliqué sur la roue (20).

2. Unité de commande selon la revendication 1, dans laquelle l'unité de commande de transition de niveau de couple tend vers l'application d'une commande en boucle ouverte sans commande d'asservissement de couple sur la base de la détection d'une faible valeur du couple de freinage appliqué sur la roue.

3. Unité de commande selon la revendication 2, dans laquelle l'unité de commande de transition de niveau de couple utilise entièrement la commande d'asservissement de couple sur la base du signal provenant du capteur de couple en résultat du dépassement par le signal d'un seuil prédéterminé.

4. Unité de commande selon la revendication 1, dans laquelle les circuits destinés à régler l'instruction de sortie de couple de freinage réalise des transitions entre une commande sensiblement en boucle ouverte de l'instruction de sortie de couple de freinage indépendamment du couple de freinage mesuré et une commande asservie sensiblement en boucle fermée de l'instruction de sortie de couple de freinage sur la base du couple de freinage mesuré en fonction du couple de freinage mesuré.

5. Unité de commande selon la revendication 4, dans laquelle l'unité de commande de transition de niveau de couple réalise des transitions entre une commande en boucle sensiblement ouverte de l'instruction de sortie de couple de freinage et une commande asservie sensiblement en boucle fermée de l'instruction de sortie de couple de freinage sur une plage de couple de freinage mesuré en fonction du couple de freinage mesuré.

6. Unité de commande selon la revendication 5, dans laquelle la fonction est représentée par une équation du premier ordre.

7. Unité de commande selon la revendication 5, dans laquelle la fonction est représentée par une équation du deuxième ordre ou une équation d'ordre supérieur.

8. Unité de commande selon la revendication 4, dans laquelle une fréquence à laquelle l'unité de commande de transition de niveau de couple réalise des transitions est commandée.

9. Unité de commande selon la revendication 1, dans laquelle l'unité de commande devient moins sensible ou insensible à la valeur mesurée de couple de freinage appliqué sur la roue à des niveaux de couple de freinage faibles.

10. Dispositif de commande d'un couple de freinage appliqué sur une roue d'un véhicule comprenant ;

l'unité de commande selon la revendication 1 ; et

un capteur de couple, couplé de manière opérationnelle à l'actionneur et ensemble de freinage et à l'unité de commande de transition de niveau de couple afin de mesurer une valeur de couple de freinage appliqué sur la roue et réinjectant un signal à l'unité de commande de transition de niveau de couple représentatif de la valeur de couple de freinage appliqué.

11. Unité de commande selon la revendication 10, dans laquelle l'unité de commande de transition de niveau de couple tend vers l'application d'une commande en boucle ouverte sans commande d'asservissement de couple sur la base de la détection d'une faible valeur de couple de freinage appliqué sur la roue.

12. Dispositif selon la revendication 11, dans lequel l'unité de commande de transition de niveau de couple utilise entièrement la commande d'asservissement de couple sur la base du signal à partir du capteur de couple en résultat du dépassement, par le signal, d'un seuil prédéterminé.

13. Dispositif selon la revendication 10, dans lequel l'instruction de sortie de couple de freinage est opérationnelle afin de commander une vanne de pression contenue dans l'actionneur et ensemble de freinage.

14. Dispositif selon la revendication 10, dans lequel l'instruction de sortie de couple de freinage est opérationnelle afin de commander une vanne d'écoulement contenue dans l'actionneur et ensemble de freinage.

15. Dispositif selon la revendication 14, comprenant, en outre, un capteur de pression destiné à mesurer la pression d'un fluide commandé par la vanne d'écoulement, la pression étant représentative d'une valeur d'un effort de freinage appliqué sur la roue, et dans lequel l'unité de commande de transition de niveau de couple reçoit la sortie du capteur de pression afin de réaliser une commande de pression en boucle fermée à de faibles niveaux de couple.

16. Dispositif selon la revendication 10, dans lequel le véhicule est un avion.

17. Dispositif selon la revendication 10, dans lequel le véhicule est une automobile.

18. Dispositif selon la revendication 10, dans lequel l'unité de commande de transition de niveau de couple réalise des transitions entre une commande sensiblement en boucle ouverte de l'instruction de sortie de couple de freinage indépendamment du couple de freinage mesuré et une commande d'asservissement sensiblement en boucle fermée de l'instruction de sortie de couple de freinage sur la base du couple de freinage mesuré en fonction du couple de freinage mesuré.

19. Dispositif selon la revendication 18, dans lequel l'unité de commande de transition de niveau de couple réalise des transitions entre une commande sensiblement en boucle ouverte de l'instruction de sortie de couple de freinage et une commande d'asservissement sensiblement en boucle fermée de l'instruction de sortie de couple de freinage sur une plage de couple de freinage mesuré en fonction du couple de freinage mesuré.

20. Dispositif selon la revendication 19, dans lequel la fonction est représentée par une équation du premier ordre.

21. Dispositif selon la revendication 19, dans lequel la fonction est représentée par une équation du deuxième ordre ou d'un ordre supérieur.

22. Dispositif selon la revendication 18, dans lequel une fréquence à laquelle l'unité de commande de transition de niveau de couple réalise des transitions est commandée.

23. Dispositif selon la revendication 18, dans lequel le véhicule est un avion.

24. Dispositif selon la revendication 18, dans lequel le véhicule est une automobile.

25. Procédé de commande d'un couple de freinage appliqué sur une roue (20) d'un véhicule comprenant les étapes de ;

réception d'une instruction de couple de freinage représentative d'une valeur désirée du couple de freinage à appliquer sur la roue (20) et fourniture d'une instruction de sortie de couple de freinage à un actionneur et ensemble de freinage (16) qui applique un couple de freinage sur la roue (20) sur la base de l'instruction de sortie de couple de freinage ;

mesure d'une valeur de couple de freinage appliqué sur la roue (20) et utilisation d'un signal représentatif de la valeur de couple de freinage appliqué afin de réaliser une commande d'asservissement de couple à partir de l'instruction de sortie de couple de freinage ; et

réglage de l'instruction de sortie de couple de freinage délivrée à l'actionneur de frein (16) en utilisant la commande d'asservissement de couple sur la base de la valeur mesurée de couple de freinage, l'étape de réglage comportant une étape de limitation d'un degré de la commande d'asservissement de couple sur la base de la valeur de couple de freinage appliqué sur la roue.

26. Procédé selon la revendication 25, dans lequel l'étape de limitation comporte la transition vers l'application d'une commande en boucle ouverte sans la commande d'asservissement de couple sur la base de la détection d'une faible valeur de couple de freinage appliqué sur la roue.

27. Procédé selon la revendication 26, dans lequel l'étape de limitation comporte l'utilisation complète de la commande d'asservissement de couple sur la base du signal provenant du capteur de couple en résultat du dépassement, par le signal, d'un seuil prédéterminé.

28. Procédé selon la revendication 25, dans lequel l'étape de réglage comporte, en outre, la transition entre une commande sensiblement en boucle ouverte de l'instruction de sortie de couple de freinage indépendamment du

couple de freinage mesuré et une commande d'asservissement sensiblement en boucle fermée de l'instruction de sortie de couple de freinage sur la base du couple de freinage mesuré en fonction du couple de freinage mesuré.

29. Procédé selon la revendication 28, dans lequel l'étape de transition comporte la transition entre une commande sensiblement en boucle ouverte de l'instruction de sortie de couple de freinage et une commande d'asservissement sensiblement en boucle fermée de l'instruction de sortie de couple de freinage sur une plage de couple de freinage mesuré en fonction du couple de freinage mesuré.

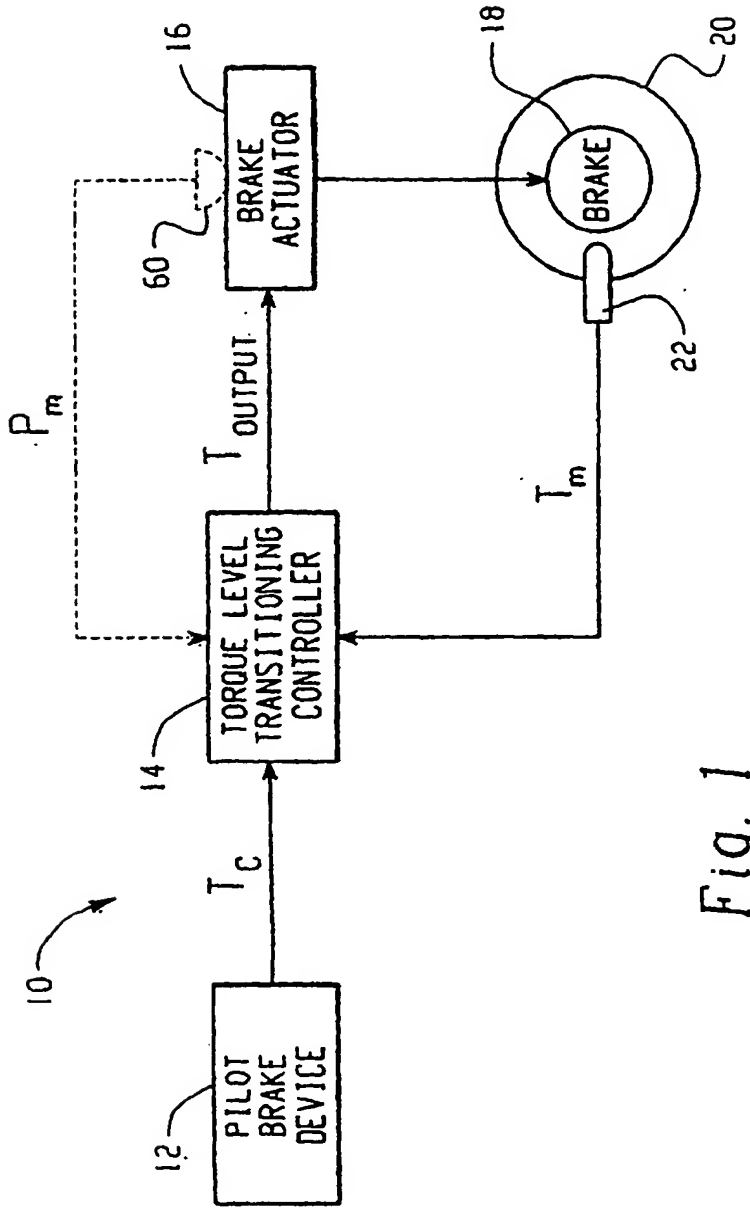

10
12
PILOT BRAKE DEVICE
14
TORQUE LEVEL TRANSITIONING CONTROLLER
16
BRAKE ACTUATOR
18
BRAKE
20
22
60
T_c
T_{OUTPUT}
T_m
P_m

Fig. 1

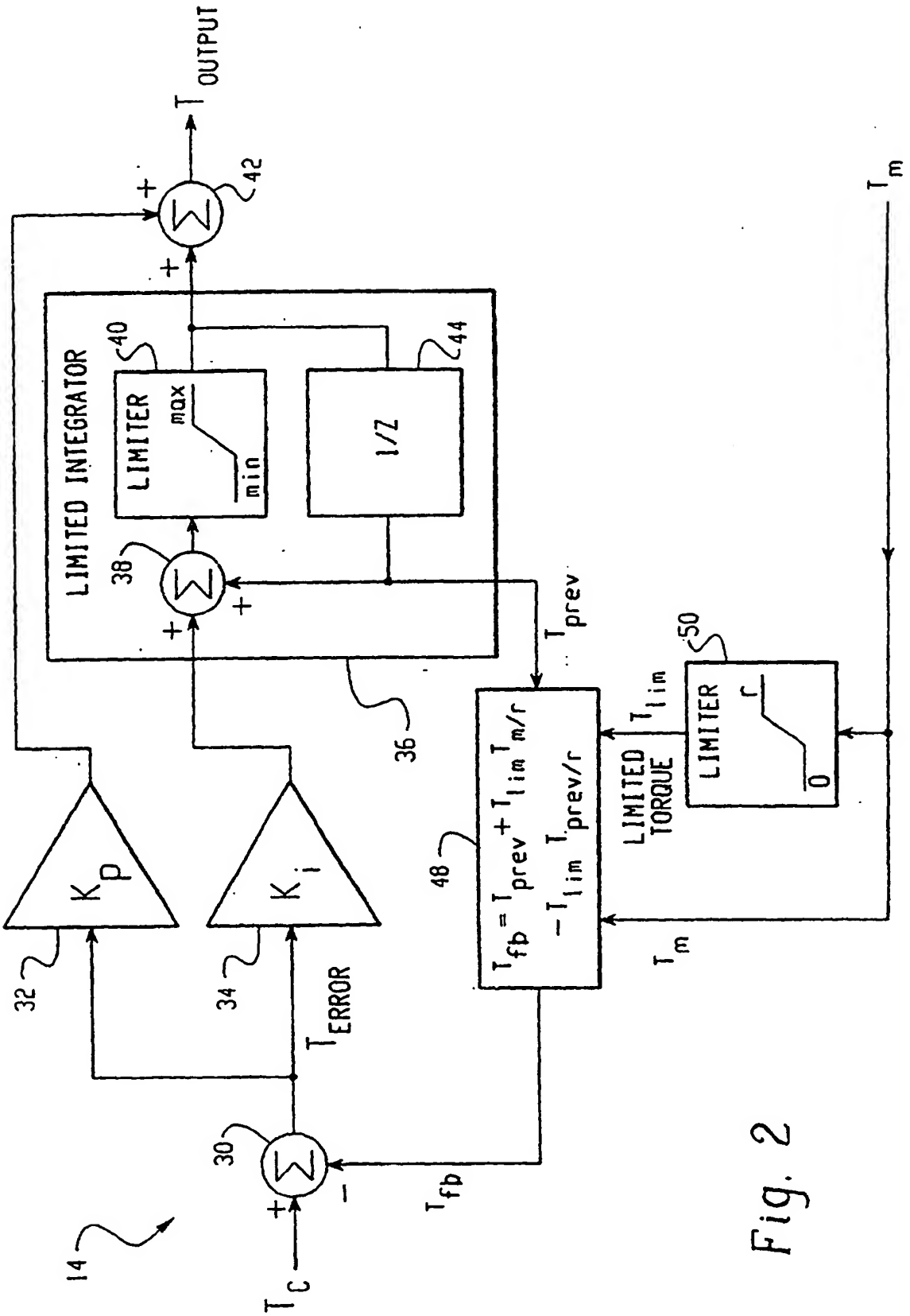
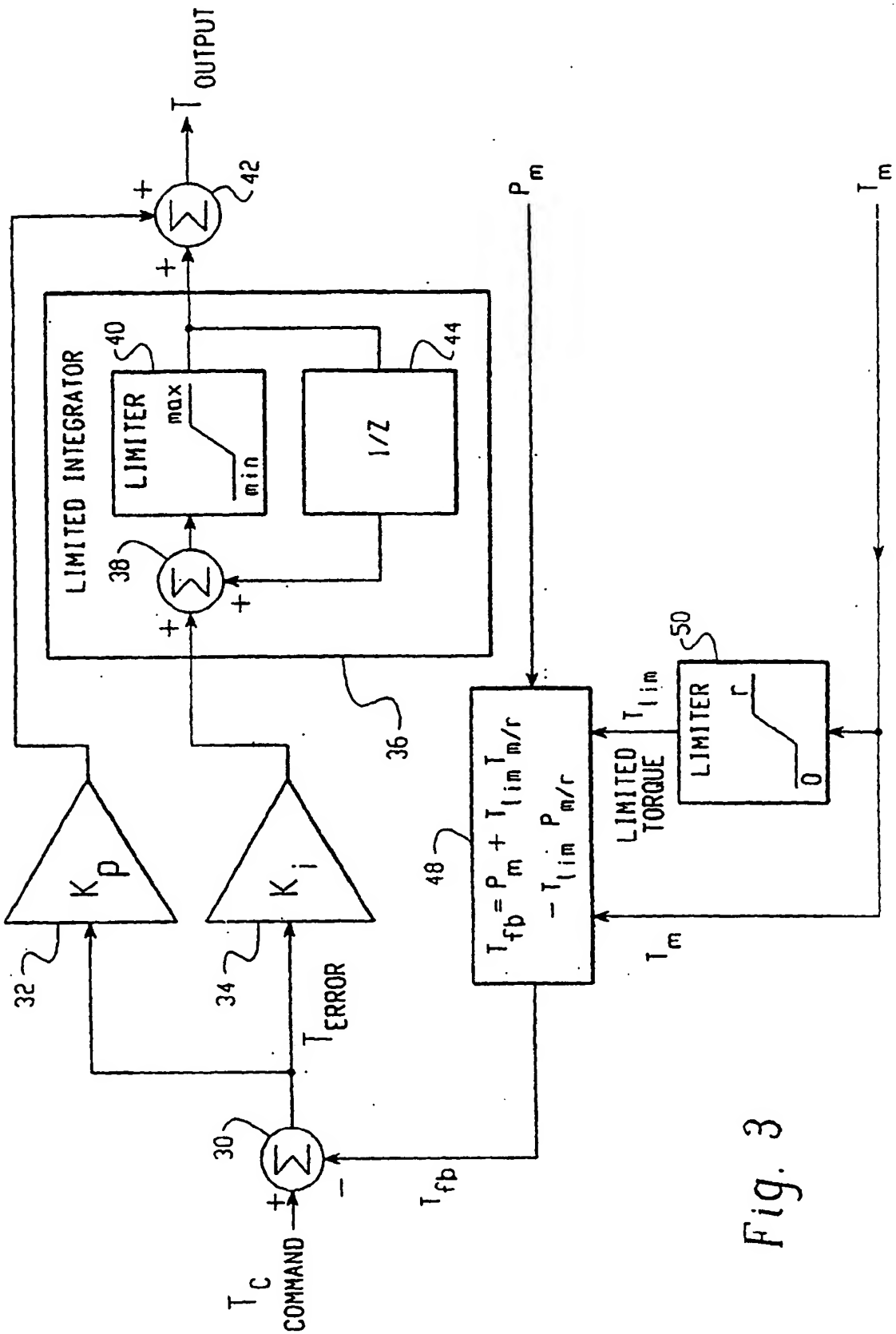

T OUTPUT
42
LIMITED INTEGRATOR
40
LIMITER
max
min
1/Z
44
38
T prev
36
50
LIMITED TORQUE
T lim
LIMITER
r
0
T m
48
T fb = T prev + T lim T m/r - T lim T prev/r
T m
K p
K i
32
34
T ERROR
30
T fb
T c
14

Fig. 2


T OUTPUT
42
LIMITED INTEGRATOR
40
LIMITER
max
min
1/Z
44
38
36
K_p
K_i
32
34
30
T_{ERROR}
T_c
COMMAND
T_{fb}
P_m
T_m
48
$T_{fb} = P_m + T_{lim} T_{m/r} - T_{lim} P_{m/r}$
LIMITED TORQUE
T_{lim}
50
LIMITER
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0
T_m

Fig. 3

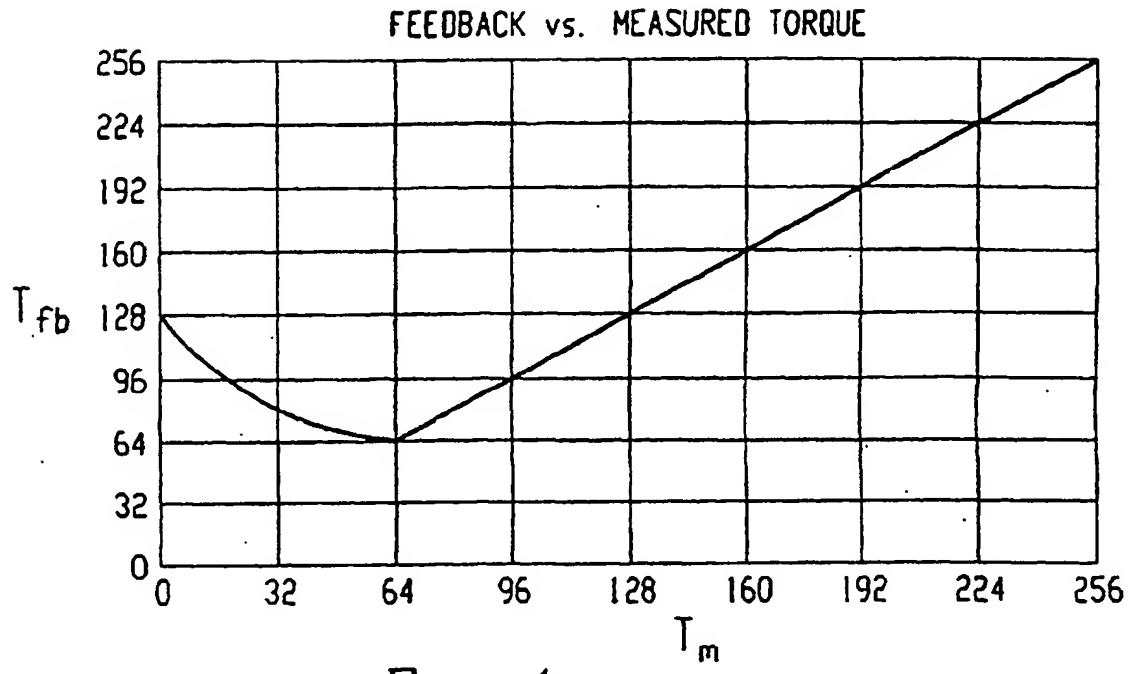

FEEDBACK vs. MEASURED TORQUE
256
224
192
160
128
96
64
32
0
T_{fb}
0
32
64
96
128
160
192
224
256
T_m

Fig. 4a

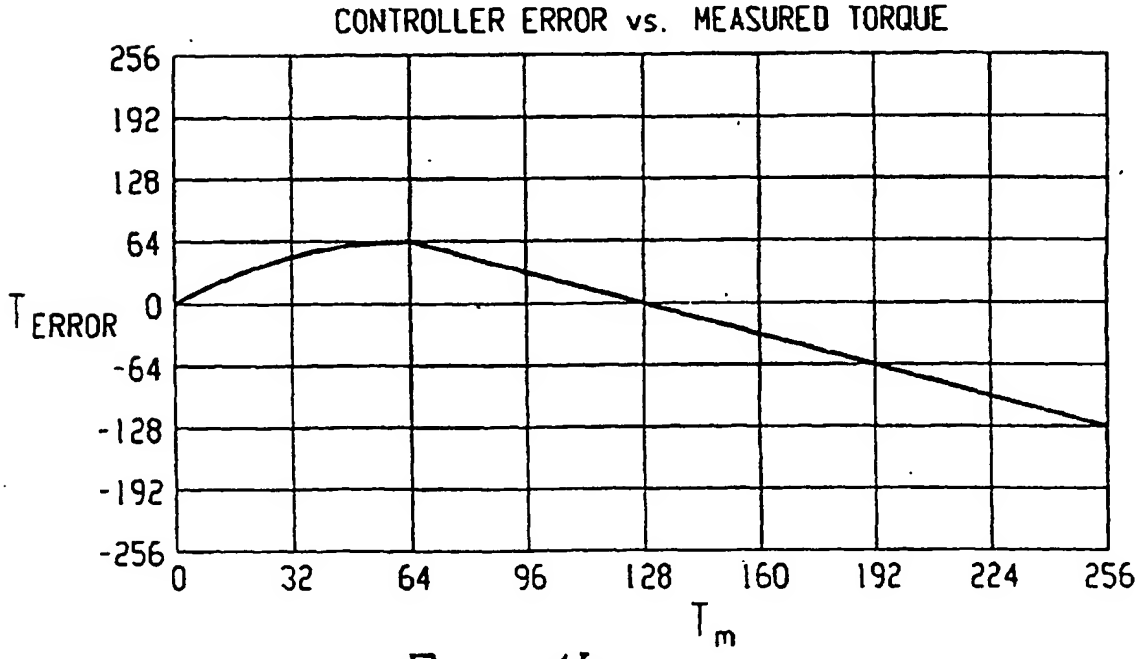
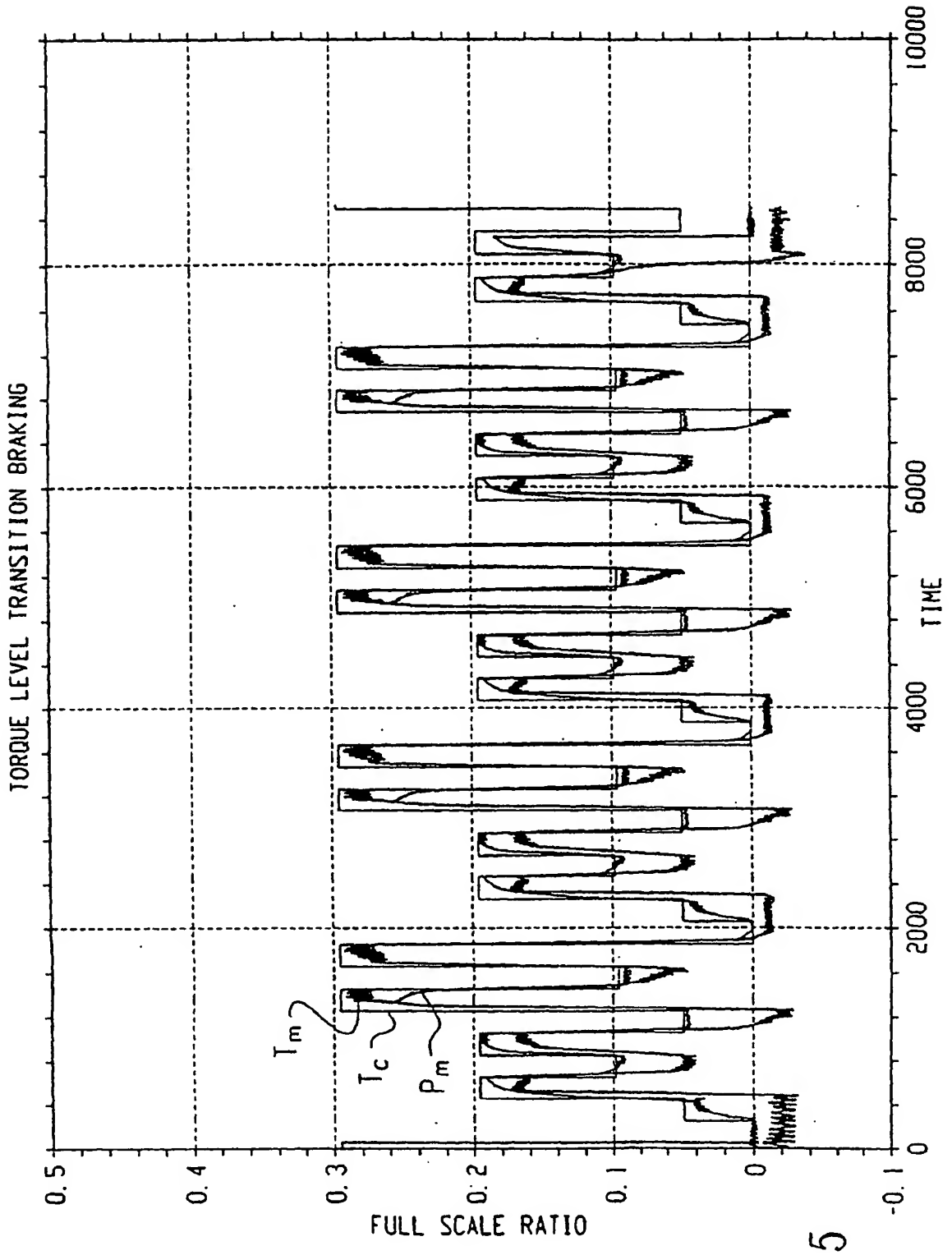

CONTROLLER ERROR vs. MEASURED TORQUE
256
192
128
64
0
-64
-128
-192
-256
T_{ERROR}
0
32
64
96
128
160
192
224
256
T_m

Fig. 4b


TORQUE LEVEL TRANSITION BRAKING
FULL SCALE RATIO
TIME
0.5
0.4
0.3
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4000
6000
8000
10000
T_m
T_c
P_m

Fig. 5

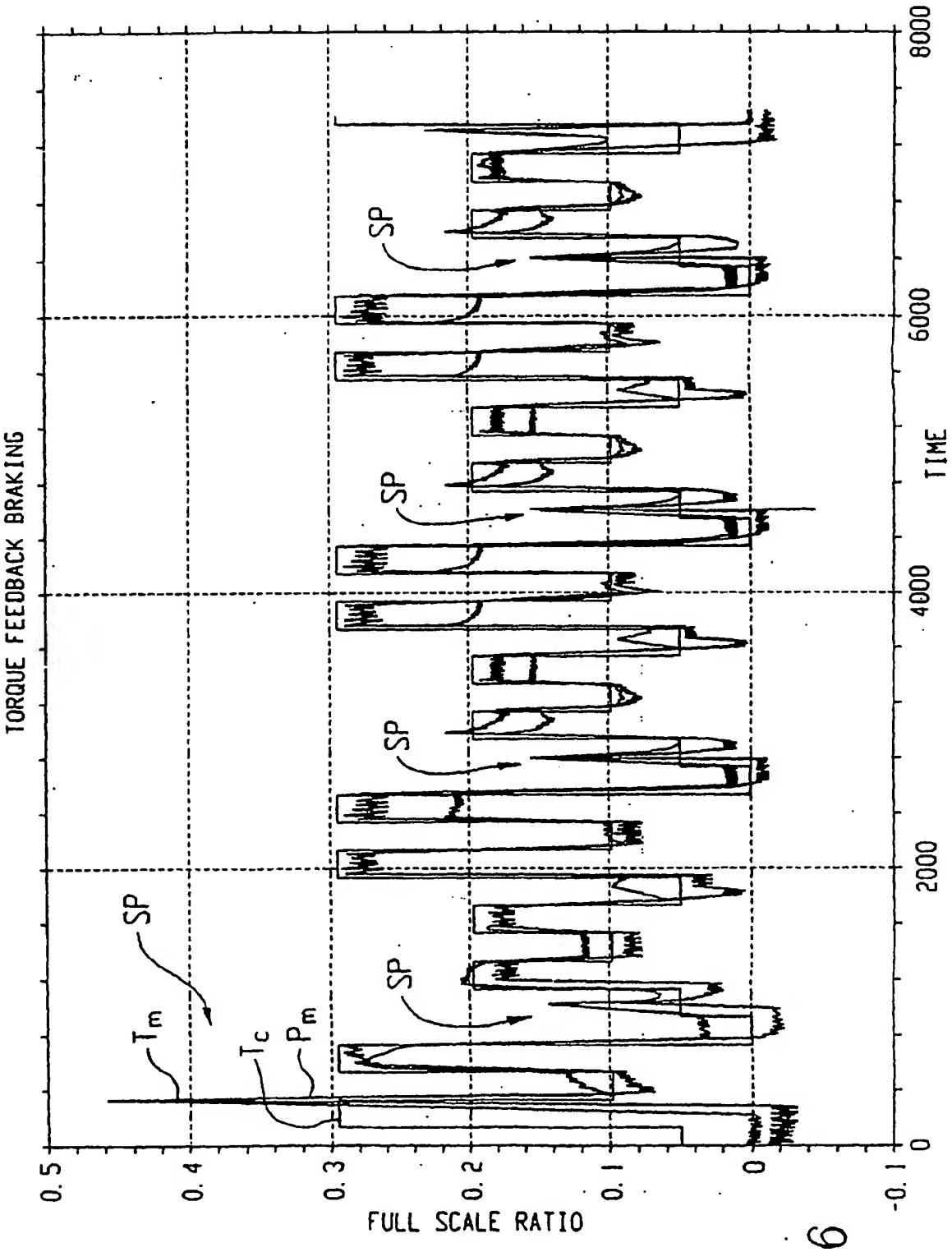
TORQUE FEEDBACK BRAKING
FULL SCALE RATIO
TIME
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
2000
4000
6000
8000
SP
SP
SP
SP
SP
T_m
T_c
P_m

Fig. 6